INTEGRATION OF PHOTOGRAMMETRIC AND GEOGRAPHIC DATABASES

Peggy Agouris
Anthony Stefanidis

Department of Spatial Information Science and Engineering
and the National Center for Geographic Information Science and Analysis
University of Maine
5711 Boardman Hall, Rm. 348
Orono, ME 04469-5711
Tel: (207) 581 2180, Fax: (207) 581 2206, e-mail: {peggy, tony}@spatial.maine.edu

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ABSTRACT

This paper addresses the role of digital photogrammetry within the current trend towards integrated databases, comprising photos and maps in digital format, relevant additional information in raster or vector format (e.g. extracted features and DEMs), as well as a set of interrelating operations (e.g. feature extraction algorithms, georeferencing). The relationship between photogrammetry and integrated geographic systems is bi-directional. From digital images, through georeferencing, object extraction and DEM generation, information for geodatabase layers is obtained. At the same time, information from geographic databases is used to guide photogrammetric operations, especially for updating purposes (e.g. using previously available DEMs for deriving approximate conjugate locations, or using vector feature information for updating). In this paper we present the state-of-the-art in relevant digital photogrammetric research issues, and focus in particular on automatic orientations, DTM and orthoimage generation, and man-made object extraction. We evaluate how the current form of these algorithms and corresponding research activities meet the needs of such integrated environments, in terms of accuracy, efficiency, and productivity, and we identify research trends and needs resulting from this integration.

1. INTRODUCTION

The qualitative and quantitative geoinformation contained in spatial databases like maps, topographic databases, and GIS in general, is of vital importance to a large, multifaceted array of applications. During the last few years, mainly due to the increased awareness of the economical consequences and importance of organized planning and spatial information management, the number of users, and consequently the demand for such data, is steadily increasing. The spatial information user community has expanded well beyond its traditional limits, even making the transition towards non-professional users, with novel forms of spatial information (e.g. mapping data on CD-ROM) being nowadays available to the general public.

In addition to the increased demand for spatial geoinformation, the accelerated rate of change in modern environments makes the frequent updating of spatial databases rather imperative to ensure their continuous validity. Photogrammetry surpasses existing alternative methods for geodata collection in terms of accuracies over involved costs, offering unmatched potential for fast collection of large amounts of accurate spatial information.

The great advancements of the last decade in the field of digital photogrammetry have further solidified the role of photogrammetry as data collection methodology, allowing the bypassing of the need for expensive, dedicated instruments and trained personnel. We are currently at the stage where automation through the use of digital imagery and suitable image analysis techniques is making the transition from research and development to production, with softcopy workstations appearing set to substitute analytical instruments as the choice of the practitioners. However, while research and development activities in digital photogrammetry so far mainly concentrated on improving the performance of photogrammetric operations through automation (with undoubtedly remarkable results), another great advantage of digital photogrammetry remains rather unexplored: the compatibility of digital imagery with other geographic databases in terms of storage formats, analysis operations, and media, which permits the full integration of digital imagery in spatial geoinformation systems.

The realization of the potential for the integration of digital imagery in GIS can be traced back to the beginning of the decade [Ehlers et al., 1989; Ehlers et al., 1991; Dobson, 1993; Gahegan, 1994; Ehlers et al., 1994]. The initial concepts though were focusing on remote sensing rather than photogrammetry, as reliable digital imagery was associated solely with remote sensing applications. However, advancements in digital photogrammetry allow us to reevaluate this concept. In this paper we will discuss the major issues associated with this integration focusing on aerial imagery, and we will try to evaluate the current state-of-the-art in photogrammetric research pertaining to it.

2. INTEGRATED PHOTOGEOGRAPHIC DATABASES

Geographic information systems deal with acquiring, storing, retrieving, modeling, analyzing and displaying qualitative and quantitative information on spatially related data. The involved data are quite diverse, ranging for example from land use models and scanned maps to DEMs, and they exist in a variety of types and formats [Ehlers et al., 1991]. The information conveyed by these data describes position, topology, and attributes of entities.

Regarding image data, and despite the rather obvious importance of imagery in describing geographic information, GIS and image analysis processes can be currently considered complementary but not yet fully integrated, with GIS beginning where image analysis ends. The situation is very effectively described in [Berry, 1995] where GIS and image analysis are presented as being the realm of specialists in segregated offices "down the hall and to the right". Indeed, in current practice, imagery is employed as data source for geoinformation extraction through image analysis methods. The resulting information is subsequently introduced in a GIS, but the imagery itself is not functionally incorporated in it, with few notable exceptions on display-oriented tasks (e.g. display of georeferenced data overlaid on image data). Thus, information flow between image analysis and GIS is one-directional and communication is rather minimal (Fig. 1).

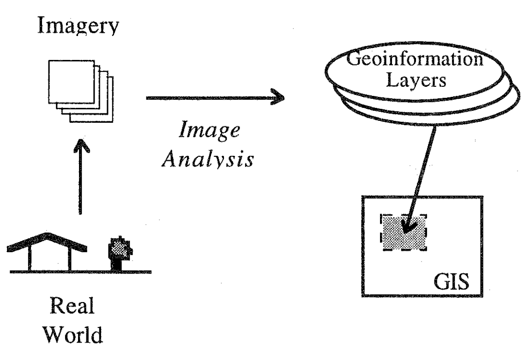

Fig. 1: Image Analysis and Geographic Information Systems: information flow in a non-integrated environment.

With the use of digital imagery, the physical, integration-prohibiting obstacles caused by the incompatibility of analog imagery and digital geoinformation are eliminated, opening the way for full integration. It has to be noted here that the full integration of digital imagery in a GIS refers not only to the storage and management of raster image files within a geoinformation system, but also to the embedding of image analysis operations within such a system, with these operations supporting as well as being supported by relevant existing geographic information. Thus, an integrated environment is characterized by bi-directional information flow (Fig. 1), as:

- geoinformation produced through image analysis operations is introduced into the GIS (similarly as before), but furthermore
- existing geoinformation can be used to support image analysis operations, and
- the images themselves are introduced in the GIS, with their management and operations supported by the integrated database environment, and supporting relevant GIS tasks.

The term *photogeographic* is used in this paper to refer to such an integrated environment, to emphasize the role of imagery within it. An integrated photogeographic environment allows the optimal exploitation of the interrelationships which exist among different databases. These interrelationships are *spatial*, resulting from overlaps in the object space, and *temporal*, existing when various databases express the state of the object space at different time instances. This is obviously the case when multitemporal imagery is involved, or is even the norm when imagery is integrated with data collected through other methodologies.

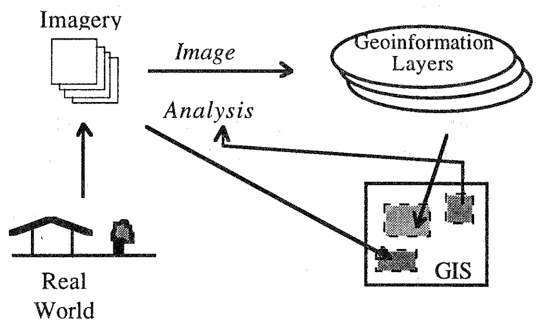

Fig. 2: Iinformation flow in an integrated photogeographic environment.

The full exploitation of an integrated photogeographic environment allows digital photogrammetry to become a key component within GIS, with a role surpassing its current as data input method.

3. PERTINENT PHOTOGRAMMETRIC ADVANCEMENTS

Among the substantial photogrammetric advancements of the last 15 years, the advancements in research topics which deal with image orientations, DTM and orthophoto generation, and object geoinformation extraction are the ones which are most affecting the move towards integrated photogeographic information environments, supported by the developments in softcopy workstations. The special value of these issues for integration lies mainly on their fundamental role for geopositioning an image and the information extracted from it.

3.1 Orientations and Aerotriangulation

Orientations and aerotriangulation are essential as they permit the positioning of imagery in space, and subsequently, the introduction of this imagery and information extracted from it in a GIS. Automation in these fields came through the use of digital imagery and image analysis techniques.

Regarding relative orientation, the method in [Schenk et al., 1991] employs edge detection for selecting matching candidates which are subsequently precisely matched by examining their correlation coefficients. Through the use of image pyramids, matching is fine-tuned and precision is improved. Reported accuracies in conjugate identification through this automated method reach 0.2 pixel, which corresponds to 5-6 μm at the finest resolution used in the reported experiments [Stefanidis et al., 1991]. In a conceptually similar approach, [Tang & Heipke, 1996] use geometric coherency constraints and report conjugate point measurement accuracies on the order of 0.2-0.3 of a pixel, which at the finer used resolutions correspond to approximately 3.5 μm. In addition to the above mentioned accuracies, which are comparable to the ones associated with high-precision analytical photogrammetric processes, the automated orientation methods offer excellent time performance (as little as 4 minutes per image pair) and produce very large numbers of conjugate points per image pair, outperforming analytical methods in these tasks.

An excellent review of digital matching strategies for point transfer is given in [Foerstner, 1995]. Automated point transfer based on graph theory models for the selection of proper matching combinations has been extended into a digital aerotriangulation strategy, with accuracies on the order of 0.3-0.4 pixels [Ackermann & Tsingas, 1994]. In an alternative approach, multiple image multipoint matching is used for the automatic determination of exterior orientation parameters and positioning of selected points within an aerotriangulation strategy [Agouris, 1992]. The method proceeds by employing automatic orientation modules for the automatic generation of approximate photomosaics. Using these photomosaics, approximate conjugate points are selected and are subsequently matched precisely by using a modified least squares based matching solution. Thus, the technique combines matching and block adjustment, achieving accuracies on the order of 0.3 pixel at the finer resolution [Agouris, 1992]. For reasonable resolutions this can correspond to measuring accuracies of 3-5 μm.

3.2 Automated DTM and Orthoimage Generation

DTMs and orthoimages are traditionally two of the most popular and fundamental geoinformation layers at GIS. Their automation through digital photogrammetry is having a major effect in underlining the potential benefits of an integrated photogeographic information environment.

Automated Digital Terrain Model generation has resulted from the application of matching techniques to a very large amount of points in a stereopair of digital images. The matching solutions define pairs of conjugate points, and when projected in object space they determine terrain points. These points are used for the definition of a DTM. Quite often, various geometric constraints are imposed, tying together solutions of various points, to ensure geometric coherence in the object space. The processed points can be selected to form a grid, or be randomly distributed.

Packages for automated DTM generation from digital imagery (e.g. MATCH-T) have made the transition from research into production, becoming available in softcopy photogrammetric workstations (e.g. Leica/Helava DPW 770, VirtuoZo). Initial experiments comparing the performance of such systems to top-of-the-line analytical plotters were rather satisfactory, with deviations between automatically and manually determined DTMs being on the order of 0 to 2 m for 1:10000 scale photography and very adverse terrain (e.g. a glacier area, with abrupt and severe height variations) [Baltsavias et al., 1996]. Better accuracies can be achieved for more regular types of terrain. Employing 1:16000 scale imagery and a DPW system, [Mikhail, 1992] reported DTM accuracies in the orded of 0.4-1.0 m relative to the heights derived with state-of-the-art analytical methods. For images of scale 1:9000 [Walker, 1994] reports accuracies on the order of 0.009-0.018% of the flying height for DTMs automatically determined using MATCH-T.

Orthoimages have enjoyed increased popularity with the transition from analytical to digital photogrammetry, as they are easy to produce, very suitable for overlay on other geodata, and can complement, or even substitute, topographic maps. They convey great amounts of information and can be considered excellent base maps. Regarding production, performance and functionality, digital orthoimage generation has already surpassed its analog counterpart, and has very successfully made the transition to production, with numerous firms offering systems or software modules for orthoimage generation [Baltsavias, 1993]. Considering both algorithmic and production aspects, the issue of orthoimage generation is considered to have reached a satisfactory and rather stable level.

3.3 Automated Extraction of Objects from Digital Imagery

The current state-of-the-art among digital image analysis and computer vision activities on the subject of automated object extraction from digital imagery can be found in [Gruen et al., 1995]. Among the digital photogrammetric research topics pertinent to GIS integration, this is the one where a dominant methodological/algorithmic trend aiming at automation has not yet clearly emerged. Instead, we can identify numerous approaches and various strategies developed, often aiming at specific subtasks (e.g. identifying only roads on high altitude imagery) with various degrees of success. Among the emerging trends, monoplotting appears to combine operational ease with the potential for high accuracy measurements in an operator-assisted mode [Agouris et al., 1994]. Despite the lack of a common algorithmic trend, a clear operational trend is evident: to remove time-consuming and error-prone measuring tasks from the operator's duties by performing them instead through automated modules. The role of an operator in a modern digital photogrammetric object extraction process is expected to become limited to guiding the execution of automated measuring modules, and to providing logical decisions (e.g. is this a road or a river?), which are the most difficult to successfully automate.

The advancements in the above research topics are supported by developments in softcopy photogrammetric workstations [Heipke, 1995], which are slowly but steadily gaining the trust of practitioners. Their advantages can be summarized as

- operational ease, with cumbersome observation and measuring tasks substituted by computer-executed tasks,
- versatility, as limitations associated with analog and (less so) analytical instruments are naturally bypassed by softcopy systems, while at the same time the compatibility with other parts of the geoinformation environment is optimized, and
- cost-effectiveness, as they are less expensive than their analytical counterparts, and in addition offer, through automation, better time performance in their intended operations.

When examining the performance of digital orientations, aerotriangulation and other operations, and comparing them to analytical processes, one must not ignore that, beyond accuracies, operational ease and user-friendliness are essential issues influencing the choice of the practitioners. Thus, while some of the above operations (e.g. orientations) are performing accuracy-wise equally to analytical methods, the immense potential offered by automation (e.g. the simultaneous measurement of hundreds of conjugate points in a stereopair within few minutes) make digital operations overall superior to analytical ones.

4. EFFECTS OF INTEGRATION ON GIS

From an image analysis point-of-view, and beyond the obvious practical database issues associated with the integration of large raster files and relevant vector/object data in a GIS, the most important effects of photogeographic integration on GIS can be classified under two broad categories, namely GIS multidimensionality and the integration of accuracy information.

4.1 GIS Multidimensionality

Currently, typical GISs operate on a 2.5-D mode, with a single z-value attributed to a point (x,y), often through the use of DTM information. Within an integrated photogeographic information environment we are moving to full 3-D data, and furthermore, by considering the time parameter of data, to multi-dimensional operations. The move towards fully 3-D GIS is also supported by the potential for the fusion of aerial with terrain digital imagery and 3-D building models extracted from it [Streilein, 1994].

The move to 3-D GIS results from the integration of 3-D object information (e.g. buildings or 3-D vectors) extracted through image analysis methods. The transition from existing 2.5-D to full 3-D GIS is much more complex than simply adding another layer of information, which does not constitute integration [Fritsch, 1990]. Full 3-D database operations, like queries and visualization processes, would not be covered by such an extension. From a practical point of view, the extension of an already functioning GIS to accommodate a third dimension is deemed non-trivial, and database storage and management concepts and methodologies need to be properly modified to support this extension. This can be extremely difficult even for versatile object-oriented systems, thus suggesting that the development of novel prototypes appears to be a more appealing solution.

Within this broader concept, 3-D object representation is important. Boundary representations (B-Rep) are very suitable for 3-D objects, especially employing CAD, but spatial occupancy enumeration, constructive solid geometry, and cell decomposition in general (or octrees in particular), are valid alternatives for 3-D object structuring [Fritsch & Schmidt, 1995].

In addition to the third topographic dimension, the integration of digital imagery is emphasizing the role of time as a fourth dimension within GIS, thus making integrated photogeographic environments actually 4-D. Even though the temporal aspect is inherently included in current GIS applications, the use of imagery, which by nature is time-specific, is making its exploitation more pressing in database management systems (DBMS). Within this framework, geoobjects can be described by their spatio-temporal extent and behavior [Shibasaki, 1994].

4.2 Integration of Accuracy Information

Currently, photogrammetric data are typically treated within a GIS as deterministic values, ignoring spatiotemporal geometric and thematic uncertainties associated with:

- the methodologies used for their production (e.g. the algorithm employed for the generation of a DTM or the measurement of an outline),
- the quality of the data employed within these methodologies (e.g. resolution and sensor characteristics of digital imagery employed by the above methodologies), and
- the temporal validity of these data (e.g. date of capture of the imagery which was processed to produce the metadata of interest).

An integrated photogeographic environment is characterized by the multitude of data and associated sources and algorithms. Within such an environment, the proper use of information requires the identification of the uncertainty estimates associated with it for proper error propagation analysis within database operations. Thus, photogrammetrically produced data can be viewed as a specific form of fuzzy information within a GIS: they express information which is not inherently fuzzy (i.e. the outline of a building, or terrain heights), but is available with some measures of accuracy (and consequently, inaccuracy) associated with it. This is one of the critical issues differentiating the integration of digital photogrammetry vs. remote sensing within a GIS, as remote sensing is typically dealing with inherently fuzzy entities (e.g. outlines of cultivated areas).

The suitability of layer-based systems for fuzzy information representation in GISs has been much debated [Hadzilacos, 1994]. For the specific problem at hand, they are expected to be highly effective. Photogrammetric accuracy indices are typically addressing points or lines. From such indices, object positioning accuracies can be composed, in the same manner that complex objects are generated by combining points and linear elements, permitting the substitution of deterministic object outlines by more accurate probabilistic layers. Fig. 3 displays this concept, with an object outline (left) and its probabilistic representation (right). The probabilistic representation describes the existence of the object at various field locations, with field values ranging e.g. between 0 (white, lack of object) and 1 (black, definite existence of object). The figure shows how an error in measuring the building's top left corner (e.g. due to obstructions by other objects, shadows or other unfavorable radiometric conditions) is affecting the accuracy of the complete building object.

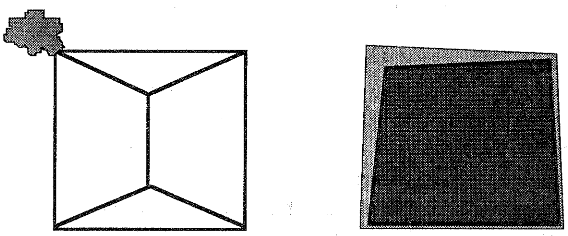

Fig. 3: An object outline (left) and its probabilistic representation (right)

This recording of accuracy estimates is very essential when considering the availability of databases of various scales and accuracies within information systems. It allows us to move towards *'objective GIS'*, where biases caused by unaccounted uncertainties in data are avoided, and thus, the subjectivity of data accuracies is removed.

5. EFFECTS ON DIGITAL PHOTOGRAMMETRY

The expected benefits of image analysis operations through their embedding into integrated photogeographic environments are related to accessing the geoinformation which already exists for the scenes they depict. Currently, typical image analysis operations aim at the automation of certain photogrammetric tasks by addressing imagery isolated from the environment in which these operations are performed. By performing these operations in an *information-supported* mode (Fig. 4), algorithmic progress can be greatly accelerated.

The logical operations which can be performed using information extracted through photogrammetric digital image analysis are of dual nature: object- or scene-oriented, with the difference between the two referring to the view of specific information alone or within a broader context. Object-pertinent logical operations are mostly consistency-oriented, and can be of geometric (e.g. examining whether the corners of an extracted building outline are orthogonal) or semantic (e.g. examining whether a complex extracted building outline actually represents muliple rather than a single building) nature. In this sense, they can be viewed rather as extensions of the individual digital image analysis modules addressing object globality, as they enhance these modules by ensuring local coherency,

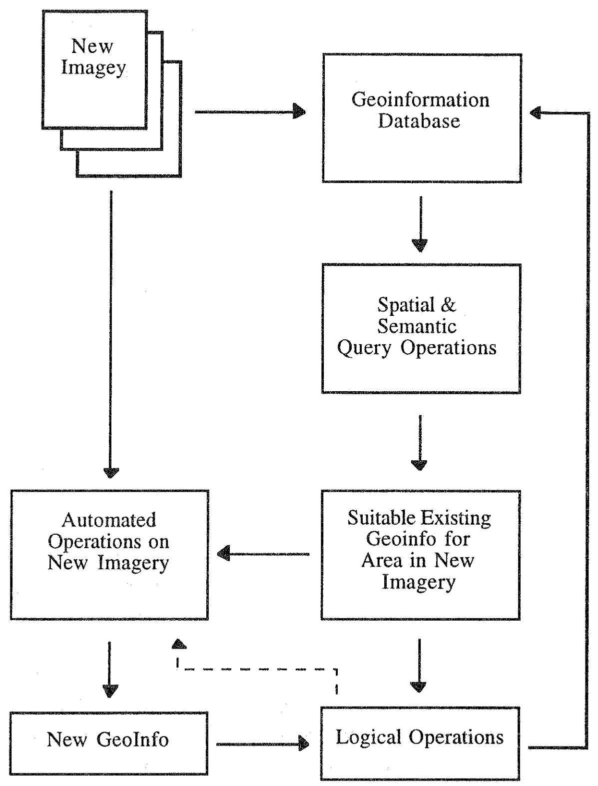

Fig. 4: Conceptual diagram of digital image analysis operations and information flow in an integrated environment

It is the database-supported scene-oriented operations though which are expected to have the most profound effect on digital photogrammetric operations. They consist of logical tests employing broader scene information, and their purpose is to examine whether the newly acquired geoinformation is consistent with the already existing one (e.g. is it possible for a road outline to be substantially higher than the local DEM values?). The role of such operations should not be considered limited to consistency checks, but rather it should be viewed as providing links to or triggering additional automated operations (note the interupted arrow in Fig. 4). The extraction of an object which has been modified since its last record provides leads for other potential changes. New road segments for example can signal local changes in buildings or land use and vice versa. Thus, suitable algorithms should be employed to examine whether these tied-in occurancies have indeed taken place, and if so to record their effects on geoinformation. In a similar manner, apparent logical inconsistencies can trigger additional image analysis operations to verify or corect the extracted geoinformation. The satisfaction of logical conditions permits the updating of the geoinformation database.

The digital photogrammetric research issue which is expected to be most improved by integrated photogeographic environments is the automated extraction of objects from digital imagery, which is a fundamental GIS-oriented application. By employing previous database information to provide quantitative (e.g. position) as well as qualitative (e.g. object type) approximations, object extraction procedures can be greatly improved by minimizing the search space within which an object is sought, and using excellent approximations on the type and expected shape of the object to be extracted. Matching, an operation currently limited among digital imagery, is thus expected to evolve into an inter-database operation, with digital images matched to maps in digital format or other relevant geodatabases, for updating and augmenting them.

6. OUTLOOK

The substantial advancements in digital photogrammetry are bringing forward the full integration of digital imagery in geographic information systems. Coupled with advancements in GIS technology, this integration has become more clearly feasible. The potential gains from such an integrated photogeographic environment are expected to revolutionize not only the processes of digital information extraction and representation, but also the way in which traditional photogrammetric operations are carried out, as well as the final product offered to the public. Within this context, the role of photogrammetry for GIS data collection (through updating and database augmenting) is expected to evolve and become strengthened and more prominent, with images becoming information layers themselves, rather than simple tools for information extraction.

REFERENCES

❑ Ackermann F. & V. Tsingas (1994) *Automatic Digital Aerial Triangulation,* Proceedings 1994 ASPRS Annual Convention, Reno, NV, Vol. 1, pp. 1-12.

❑ Agouris P. (1992) *Multiple Image Multipoint Matching* for Automatic Aerotri-angulation, Ph.D. Dissertation, Dept. of Geodetic Sc. & Surveying, The Ohio State University.

❑ Agouris P, D. Stallmann & H. Li (1994) *Semi-Automatic Monoplotting on a Digital Photogrammetric Station,* Int. Archives of Photogrammetry & Remote Sensing, Vol. XXX, Part 2, pp. 146-153.

❑ Baltsavias E.P. (1993) *Integration of Ortho-Images in GIS,* in `Photogrammetric Week '93' (D. Fritsch & D. Hobbie eds.), Wichmann Verlag, Heidelberg, pp. 261-272.

❑ Baltsavias E.P., H. Li, A. Stefanidis, M. Sinning & S. Mason (1996) *Automatic DSMs by Digital Photogrammetry,* Surveying World, Vol. 4, No. 2, pp. 18-21.

❑ Berry J.K. (1995) *Heads-Up and Feet-Down Digitizing,* GIS World, Vol. 8, No. 11, pp. 34-35.

❑ Dobson J.E. (1993) *A Conceptual Framework for Integrating Remote Sensing, GIS and Geography,* PE&RS, Vol. 59, No. 10, pp. 1491-1496.

❑ Ehlers M., G. Edwards & Y. Bedard (1989) *Integration of Remote Sensing with Geographic Information Systems: A Necessary Evolution,* PE&RS, Vol. 55, No. 11, pp. 1619-1627.

❑ Ehlers M., D. Greenlee, T. Smith & J. Star (1991) *Integration of Remote Sensing and GIS:: Data and Data Access,* PE&RS, Vol. 57, No. 6, pp. 669-675.

❑ Ehlers M., D.R. Steiner & N. Faust (1994) *Integrated Geographic Information Systems (IGIS): Status and Research Issues,* Int. Archives of Photogrammetry & Remote Sensing, Vol. 30, Part 2, pp. 376-381.

❑ Foerstner W. (1995) *Matching Strategies for Point Transfer,* in `Photogrammetric Week '95' (D. Fritsch & D. Hobbie eds.), Wichmann Verlag, Heidelberg, pp. 173-183.

❑ Fritsch D. (1990) *Towards Three-Dimensional Data Structures in GIS,* EGIS '90, Amsterdam, pp. 335-345.

❑ Fritsch D. & D. Schmidt (1995) *The Object-Oriented DTM in GIS,* in `Photogramme-tric Week '95' (D. Fritsch & D. Hobbie eds.), Wichmann Verlag, Heidelberg, pp. 29-34.

❑ Gahegan M. (1994) *Formal Semantics for the Integration of Image Data into Geographic Information Systems,* in `Advanced Geographic Data Modelling' (M. Molenaar & S. De Hoop eds.), Netherlands Geodetic Commission Publications on Geodesy, No. 40, pp. 19-39.

❑ Gruen A., O. Kuebler & P. Agouris (eds.) (1995) *Automatic Extraction of Man-Made Objects from Aerial and Space Images,* Birkhaeuser Verlag, Basel.

❑ Hadzilacos T. (1994) *On Layer-Based Systems for `Undetermined' Boundaries,* Technical Report CTI-94.11.56, Computer Technology Institute, Dept. of Computer Engineering & Informatics, Univ. of Patras.

❑ Heipke C. (1995) *State-of-the-Art of Digital Photogrammetric Workstations for Topographic Applications,* PE&RS, Vol. 61, No. 1, pp. 49-56.

❑ Mikhail E.M. (1992) *Quality of Photogrammetric Products from Digitized Frame Photography,* International Archives of Photogrammetry & Remote Sensing, Vol. 29, Part B2, pp. 390-396.

❑ Schenk T., J.-C. Li & C. Toth (1991) *Towards an Autonomous System for Orienting Digital Stereopairs,* PE&RS, Vol. 57, No. 8, pp. 1057-1064.

❑ Shibasaki R. (1994) *Handling Spatio-Temporal Uncertainties of Geo-Objects for Dynamic Update of GIS Databases from Multi-Source Data,* in `Advanced Geographic Data Modelling' (M. Molenaar & S. De Hoop eds.), Netherlands Geodetic Commission Publications on Geodesy, No. 40, pp. 228-242.

❑ Star J.L., J.E. Estes & F. Davis (1991) *Improved Integration of Remote sensing and Geographic Information Systems: A Background to NCGIA Initiative 12,* PE&RS, Vol. 57, No. 6, pp. 643-646.

❑ Stefanidis A., P. Agouris & T. Schenk (1991) *Aspects of Accuracy in Automatic Orientation,* Proceedings 1991 ASPRS Annual Convention, Baltimore, Vol. 5, pp. 334-343.

❑ Streilein A. (1994) *Towards Automation in Architectural Photogrammetry: CAD-Based 3D Feature Extraction,* ISPRS Journal of Photogrammetry & Remote Sensing, Vol. 49, No. 5, pp. 4-15.

❑ Tang L. & C. Heipke (1993) *Automatic Relative Orientation of Aerial Images,* PE&RS, Vol. 62, No. 1, pp. 47-55.

❑ Walker A.S. (1994) *Analogue, Analytical and Digital Photogrammetric Workstations: Practical Investigations of Performance,* Paper presented at the Thompson Symposium (4/9) of the Photogrammetric Society, York, England.